University of Mumbai

AEROPONICS SYSTEM

Submitted in partial fulfilment of the requirements
of the degree of

Bachelor of Engineering
by
(in alphabetical order)

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Vidyalankar Institute of Technology
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Vidyalankar Institute of Technology, Wadala (E), Mumbai

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CERTIFICATE OF APPROVAL

This is to certify that the project entitled

"AEROPONICS SYSTEM"

is a bonafide work of

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the

degree of

Undergraduate in **"B.E. (Electronics and Telecommunication)"**

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Project Report Approval for Bachelor of Engineering

This project report entitled **AEROPONICS SYSTEM** by

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Examiners

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Date:

Place:

Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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DEDICATION

This thesis is dedicated to our professor **Prof. Saurabh N. Mehta** (Vidyalankar Institute of Technology, Wadala, Mumbai) who has been our philosopher and guide. He has the attitude and the substance of a genius. He continually and convincingly conveyed a spirit of adventure in regard to research and conferences and an excitement in regard to teaching.

We can’t thank enough for his tremendous support, help and patience. We feel motivated and encouraged every time we ask for his guidance and assistance in our project.

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BE EXTC 2

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1. ABSTRACT

This report presents a printer-size system for users to experiment with aeroponics, a technique of growing plants using nutrient-infused mist instead of liquid water. Because aeroponics can be carried out in vertical farms, and is a form of controlled-environment agriculture, and a type of soil-less farming, thus it is a potential partial solution to the problems in the current agricultural system, such as deforestation, low-yield and soil degradation. Aeroponics is similar to hydroponics, but has the advantage that it requires even less water than it. The report surveys a few large scale initiatives related to smart farming and aeroponics, and then presents the workings of the aeroponics growing and electronics monitoring subsystems. The report then discusses the methodology of construction, cost analysis, electronics design and software implementation details of the project.

2. INTRODUCTION

Hunger is a growing problem in the world, with an estimated 2 billion people not having "regular access to safe, nutritious and sufficient food" according to the UN in 2019.[1] Climate change, geo-political conflict, and pandemics like Covid-19 threaten food security.

The current agricultural system is unsustainable.[2] It leads to removal of water from ecosystems for irrigation, deforestation for agricultural lands; and leaching of nitrogen and phosphorus into soils, due to the use of pesticides and herbicides. Agriculture is also a major contributor to climate change, contributing to 19% of worldwide greenhouse gas emissions.[3] [1]

While there won't be any single magic solution to deal with the above problems, there are promising new approaches such as (1) vertical farming (2) controlled-environment agriculture, and (3) soil-less farming. Aeroponics combines all three of these approaches. It involves delivering water and nutrients to plants through *nutrient-infused mist*.[4]

- It can be carried out in vertical farms (ie. tall godowns or buildings), and thus requires less land, preventing deforestation. Being indoors also keeps pests and weeds out easily, eliminating the need for pesticides or herbicides.
- It uses controlled-environment agriculture, which allows you to maximise yield by controlling wavelength/intensity of light, water-level, nutrient-level, etc.
- It is a type of soil-less farming, preventing soil degradation. It also improves nutrient feeding to the roots of the plant, and prevents spread of pathogens.

Aeroponics is similar to hydroponics, as they are both types of soil-less farming, which can be carried out in vertical farms.[5] They both consume far less water than traditional farming, but aeroponics consumes even less water than hydroponics, as it uses mist instead of liquid water. Currently hydroponic systems are cheaper, easier to build at home, and easier to maintain than aeroponic systems; one reason being that mist generating devices (such as the ultrasonic atomizer used in this project) are difficult to use and maintain.

[1] Compare this to Heating and Air Conditioning (7%), Transportation (16%), Electricity (27%), Manufacturing and Construction (31%).[3]

3. OBJECTIVE OF PROJECT

The objective of our project is to provide users with a cheap, printer-sized laboratory to experiment with Aeroponics. The target users here are botany hobbyists, botany students, and professional botanists.

We know that plant growth is affected by several factors, whether or not they are grown through aeroponics.[6] Examples of such factors are: seed variety, amount of water, brightness, humidity, and temperature. By trying out various combinations of these factors, we want users to be able to find combinations which will lead to optimum plant height or fruit yield. This information can then also be useful for other people growing plants using aeroponics. Additionally, data scientists or statisticians can use this information to come up with models of plant growth, to make predictions about what the plant growth will be under a different combination of factors, not originally in the data set.

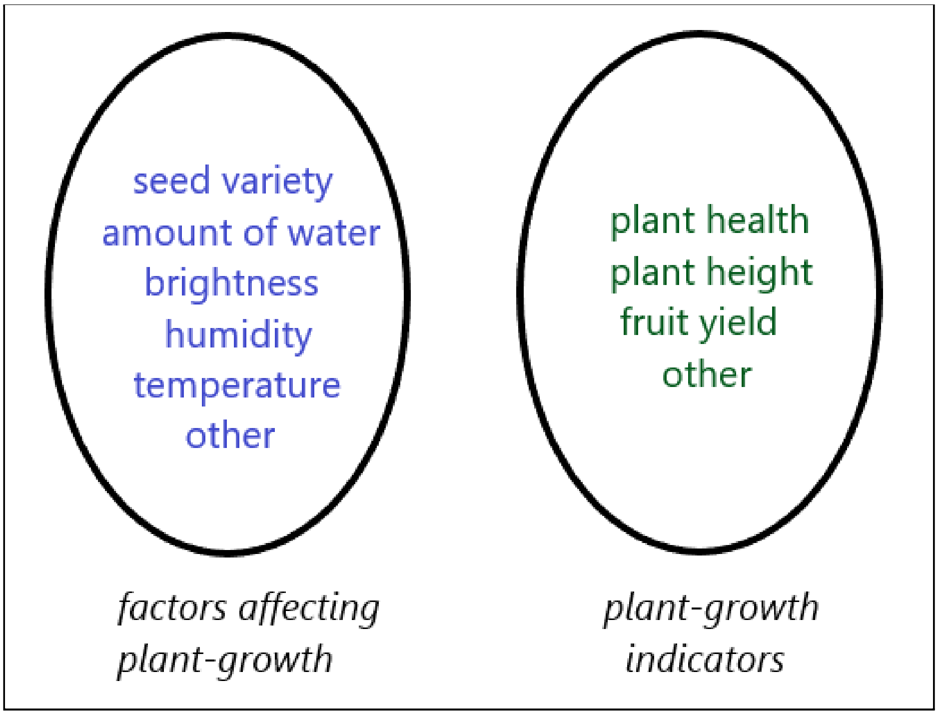

Fig 1. Plant Growth: Factors and Indicators

4. LITERATURE SURVEY

4.1. OpenAg (MIT Open Agriculture Initiative)

OpenAg was a group active from 2015 to 2020, in MIT Media Lab. Its goal was to build open resources to enable a community to accelerate Digital Agriculture/Smart Farming innovation.[7]

The main product developed by OpenAg was the **Food Computer**.[8] These are boxes the size of mini-fridges, with LEDs, sensors, pumps, fans, control electronics and a hydroponics tray. Food computers had two main purposes:

1. To allow hobbyists and schools to grow plants on their table-tops (no big garden required)
2. To experiment with "environmental recipes", and share them on the internet

An "environmental recipe" is a particular set of environmental conditions (nutrient mix, temperature, CO_2 and pH levels, light colour and intensity, etc.) under which a given species of plant grows. The idea is that even though two plants may have the same genome (genetic information), their phenome (physical traits) might differ, because of the environmental conditions. By creating a community of users who used food computers and shared their environmental recipes on the internet, OpenAg could create a Big Data set of useful, Open Source agricultural information, for everyone to use.

Unfortunately, OpenAg's food computers were unsuccessful[9]:

1. When they participated in the United Nations World Food Program (WFP), the food computers did not complete a single growth cycle. The WFP took place in a desert in Jordan, where there were hot temperatures, frequent Power Cuts and unreliable Wi-Fi; these conditions were not suitable for food computers.
2. When they collaborated with biology departments in various American schools, the teachers struggled to use their Software. The food computer was susceptible to problems like corrosion, algae, and component failure. Moreover, OpenAg did not provide Tech Support in order to Troubleshoot these problems. One teacher concluded, "food computers are not usable, because they are not user friendly".

MIT shut down the OpenAg program in 2020, after investigating allegations that plants did not grow in food computers; and also that OpenAg was discharging plant-growing solutions and dilute cleaning fluids into nearby grounds.[8]

Fig 2. Food Computers, by OpenAg.[9]

4.2. AIIRA (AI Institute for Resilient Agriculture)

AIIRA is a national research institute supported by a $20M, 5-year grant from the US National Science Foundation. Its vision is to create new AI-driven, predictive digital twins for modelling plants, and deploy them to increase the resilience of the nation's agricultural systems.[10]

Chinmay Hegde, professor at NYU Tandon School of Engineering is part of this collaboration.[11] Before working in Artificial Intelligence/Machine Learning, he worked in Signal Processing; his most cited paper is on the topic of Compressed Sensing.

According to Professor Hegde, the driving innovation behind this project are **Digital Twins**.[11] Digital twins are AI-driven simulations of the agricultural lifecycle. The agricultural life cycle involves everything from seed to plant to field to harvesting to supply chain and distribution. Currently, most decisions in the agricultural lifecycle are driven by intuition and non-experts; thus, there is huge scope for AI-driven models to help improve Decision-Making, leading to better speeds, outcomes and costs.

The problem with AI technology for agriculture is that while most AI applications involve Training Data sets with billions of Data-Points, in agriculture we don't have access to billions of images of a plant or field.[11] Thus, for these Small Data challenges, Professor Hegde suggests augmenting the limited training data with domain expertise:

- Agronomic knowledge
- Biophysics models for plants, such as rate of growth, genomics and response to stresses

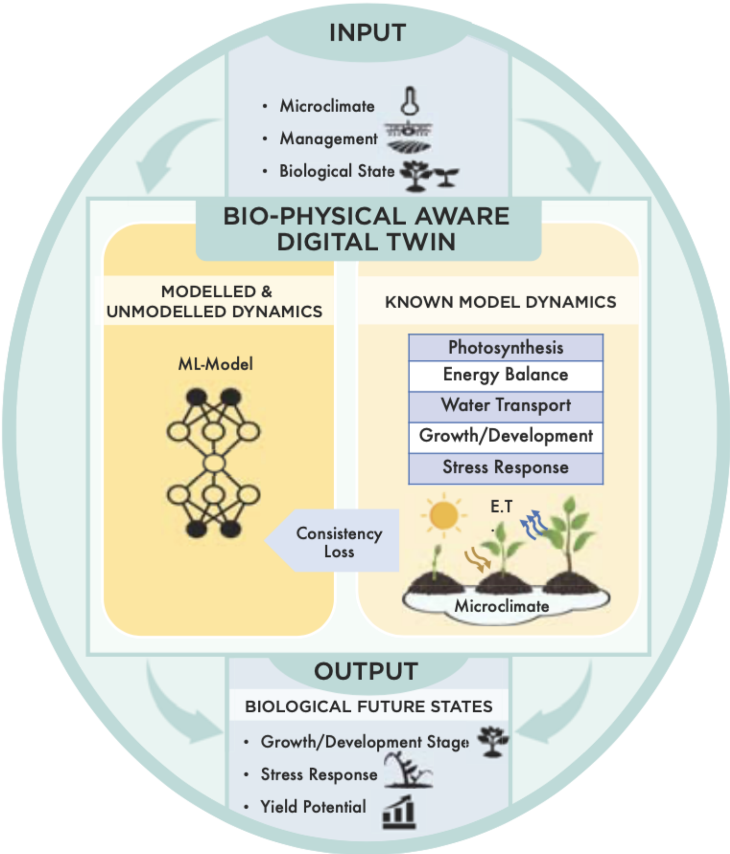

Fig 3. Bio-Physics Aware Digital Twin, by AIIRA.[12]

4.3. Aeroponics Projects in India

When we searched Google for "aeroponics india", we found a modest number of results (~3 lakh), but this was much less than "hydroponics india" (~1.14 crore). This shows that Aeroponics is relatively Neglected or considered less Important.

The top Start-Ups working in aeroponics in India are:

1. Barton Breeze, Gurgaon/Indore
2. Craft Agro, Navi Mumbai
3. Urban Farmer, Kandivali Mumbai

While aeroponics might not currently be that popular in India, the interest in Sustainable and Organic Farming is increasing drastically;[13] and thus, aeroponics too is expected to rise in popularity. Shivendra Singh- CEO of Barton Breeze and graduate from IIM Ahmedabad- believes that in the future, green vegetables will likely come from the building next to you. According to him, "a country like India with profound climate changes needs this technology more than anyone else".

5. PROBLEM STATEMENT

To create a cheap, printer-sized laboratory which lets users experiment with a new technique of growing crops called Aeroponics. Users must be able to electronically measure and track three factors (brightness,humidity, temperature), and understand how they affect plant growth. They can also experiment with Aeroponics in other, non-electronic ways, such as changing the nutrient concentration and seed type.

We know that plant growth is affected by several factors.[6] The Aeroponics System contains a brightness sensor, a humidity sensor and a temperature sensor, which can be used to measure and monitor the internal or ambient conditions of the system. This data- which is automatically saved to the cloud- can then be used along with manually collected data on plant-growth indicators (such as plant height or fruit yield) in order to quantify the relationship between plant growth and these factors.

6. PROPOSED SYSTEM

The Aeroponics System can be thought of as having 2 sub-systems:

1. Aeroponics Growing System
2. Electronics Measuring System

6.1. Aeroponics Growing System

The growing system consists of a plastic box, which houses two net-cups and a nutrient solution.[2] In each net cup, the user must fill leca clay balls, a coconut fibre pellet, and a seed of their choice (eg. cucumber, tomato, green peas, green beans, ladies finger, palak).

An ultrasonic humidifier circuit- powered by a USB cable- converts the nutrient solution into nutrient-infused mist, which delivers the nutrients efficiently to the roots of the plants.

There is also a non-electronic water level indicator, which indicates to the user when more nutrient solution needs to be added.

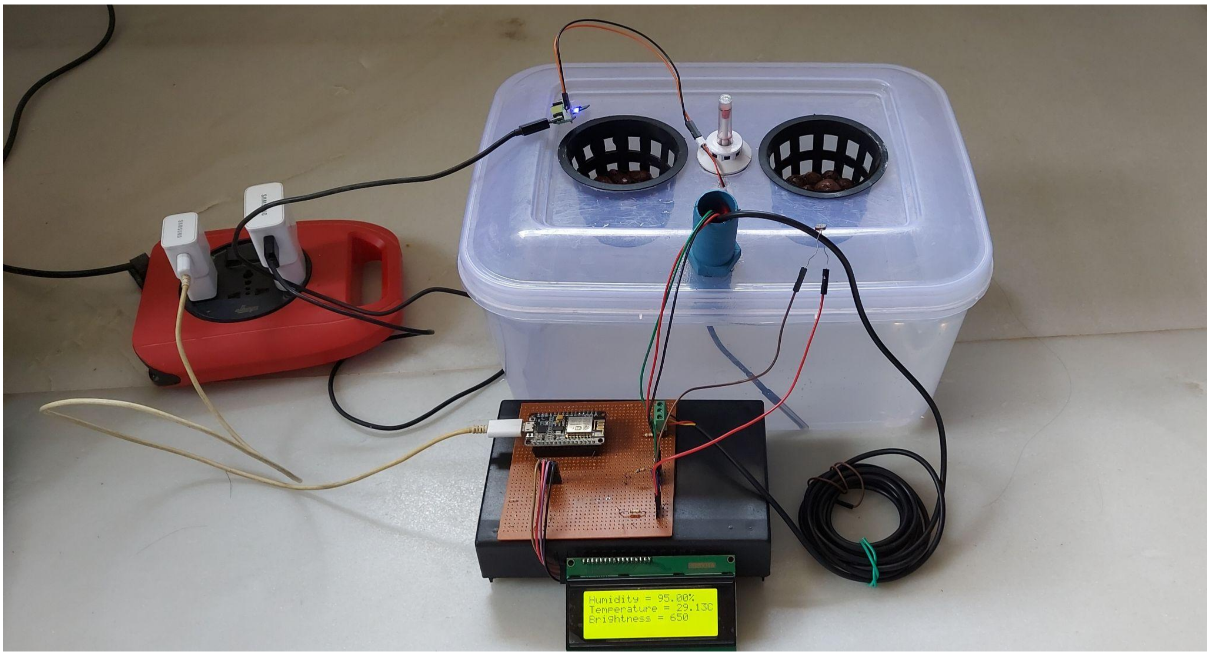

Fig 4. Photo of the Complete Aeroponics System

6.2. Electronics Measuring System

The measuring system has 3 sensors:

1. **Brightness sensor** = LDR (light-dependent resistor)
   This is used to measure how much light is being received by the plants. This can range anywhere from 0 (total darkness) to 1024 (daylight level).

[2] For our project, one can purchase any aeroponics or hydroponics nutrient solution cheaply from organic farming dealers or websites.

2. **Humidity sensor** = DHT11
   The humidity sensor module is used to measure the internal humidity of the growing system, in %. Because aeroponics involves mist-generation, this is usually quite high (upto 95%). In order to measure the internal humidity, we have provided a piece of PVC pipe where users must place the module. This ensures that the module can access the air within the system, without directly touching the water and getting wet.
3. **Temperature sensor** = DS18B20
   The temperature sensor is a long (3-metre) cable, which measures the internal temperature of the system in °C. Since it is water-proof, it can be submerged in the water directly. Like the humidity sensor, the user must insert the temperature sensor through the PVC pipe piece.

The data collected by these sensors goes to NodeMCU ESP8266, a microcontroller and IoT (internet of things) platform. This data is simultaneously:

1. Displayed on an LCD screen in Real-Time
2. Stored on ThingSpeak's cloud storage, and then displayed as a Graph[3].
   Note: Because there are a lot of data points, we are taking a 1-hour average of these points; that is, in the graph, we are taking the average of all the data collected in an hour, and showing that average.

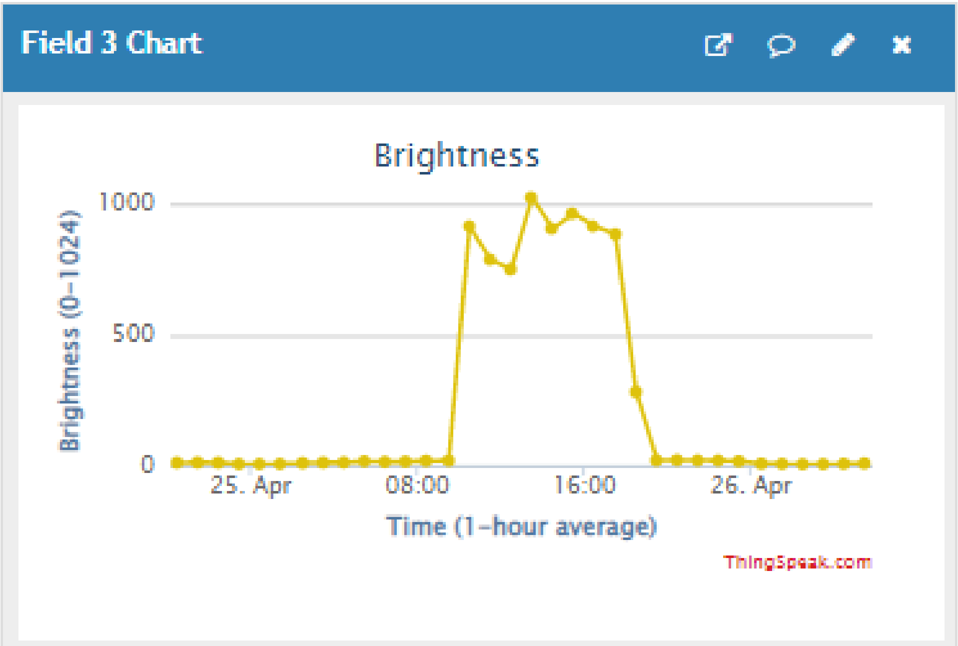

Fig 5. One of the Graphs displayed on ThingSpeak.

[3] For accessing this stored data or seeing it as a graph, we have created a ThingSpeak public channel. (see reference [14])

7. METHODOLOGY

In order to discuss methodology and cost analysis, we will divide the project into 3 parts:

1. Body
2. Electronics
3. Software

7.1. Body

Initially, our plan was to create the body of the project using techniques such as 3D Printing and CNC milling. However, we later realised that it would be cheaper and more convenient to buy a ready-made Plastic Box from the market, and use simple Hand Tools/Heat to cut out the required holes.

7.2. Electronics

Circuit.io- a free website- greatly helped us in designing the circuit. Simply by selecting the components you want from their menu, Circuit.io automatically generates a realistic, fully-colored Breadboard Circuit Diagram (see reference [15] for this diagram). It also provides a step-by-step guide to actually wiring-up this breadboard circuit. You can then transfer this breadboard circuit to a Perfboard (perforated board) or PCB (printed circuit board). Instead of soldering the components directly onto the perfboard, we soldered Berg Strips (female socket headers) onto the perfboard; this allows you to remove/replace/reuse the components as needed.

7.3. Software

Circuit.io also automatically generates the Code/Firmware for your circuit, if your circuit contains any programmable microcontroller. However, this “first draft” code needs to be Debugged and Refined- using help from online forums, documentation, DIY (do-it-yourself) tutorials, trial-and-error. The code itself is written in C/C++, and is compiled and uploaded to the microcontroller (NodeMCU ESP8266) using ArduinoIDE.

8. COST ANALYSIS

8.1. Body

#	Item	HSN	Rate (₹, no tax)	Qty	Unit	Amount (₹, no tax)
1	Plastic Box	3923	140/Pc	1	Pcs	140
2	PVC Pipe Piece	391723	20/Pc	2	Pcs	40
3	3-Inch Net Pot	6802	8/Pot	2	Pcs	16
4	Water Level Float Indicator	902610	48/Pc	1	Pcs	48
5	Leca Clay Ball		280/Kg	0.1	Kgs	28
6	Hydroponic Nutrient Solution	3102	225/Ltr [4]	0.2	Ltrs	45
7	Coconut Fibre/Peat Pellet	5305	7/Pellet	10	Pellets	70
8	Cherry Tomato Seed	1209	3/Seed	20	Seeds	60
	Total					**447**

Table 1. Cost Analysis for Body

[4] Here, "1 Ltr" refers to "1 litre concentrate", which can make 100 litres of hydroponics/aeroponics solution (half strength).[16]

8.2. Electronics

#	**Item**	**HSN**	**Rate** (₹, no tax)	**Qty**	**Unit**	**Amount** (₹, no tax)
9	10cm x 10cm Perfboard	84733030	20/Pc	1	Pcs	20
10	NodeMCU ESP8266	847141	297/Pc	1	Pcs	297
11	LCD Display 20x4	85312000	340/Pc	1	Pcs	340
12	I2C Module for LCD	854231	77/Pc	1	Pcs	77
13	DS18B20 Digital Temperature Probe (3m)	9031	152/Pc	1	Pcs	152
14	DHT11 Humidity + Temp. Sensor Digital Module	9031	120/Pc	1	Pcs	120
15	LDR GM 12528	8541	22/Pc	1	Pcs	22
16	USB Ultrasonic Humidifier Circuit Board with Atomizing Chip	8424	194/Pc	1	Pcs	194
17	Female Socket Header (Berg Strip)	8536	5/Strip of 20	1	Strip of 20	5
18	Resistor	8533	2/Pack of 5	1	Pack of 5	2
19	Single Strand Hookup Wire	8544	7/Metre	2	Metres	14
20	Male-to-Female Wire, 20cm	8544	25/Pack of 20	1	Pack of 20	25
21	5V 2A Power Supply Adapter with Micro USB Plug	8504	189/Pc	2	Pcs	378
	Total					**1646**

Table 2. Cost Analysis for Electronics

9. DESIGNING

9.1. Block and Circuit Diagrams

Our initial block diagram was more complex than the final block diagram (seen in Fig 6). The main reason for this is that our initial design was based around the Arduino ATmega32U4 microcontroller. However, we later realised that not only would using NodeMCU ESP8266 lead to a much simpler circuit, but that the latter is also cheaper than the former.

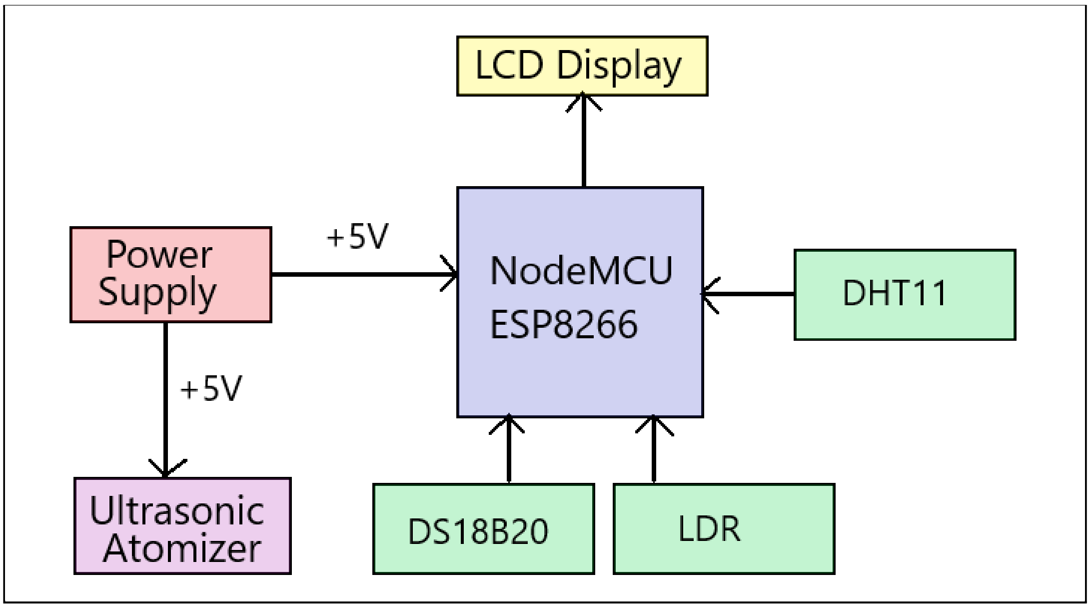

Fig 6. Electronics Block Diagram

Here is the diagram created with help of Circuit.io (see Reference [15] for seeing it in more detail):

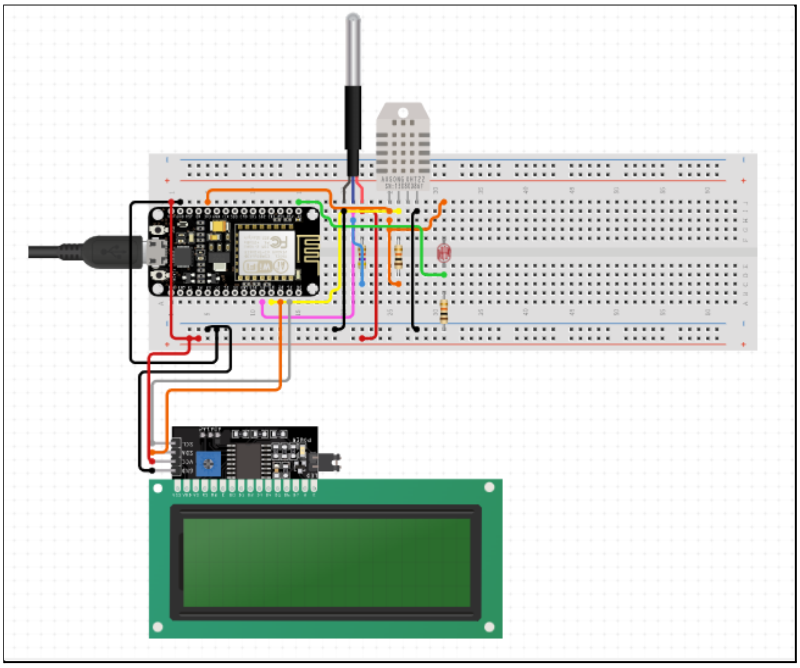

***Fig** 7*. Circuit.io Diagram[15]

And finally, here is the schematic circuit diagram. Note that we are not including the ultrasonic atomizer in the two circuit diagrams, because it is powered by a separate 5V wall adapter.

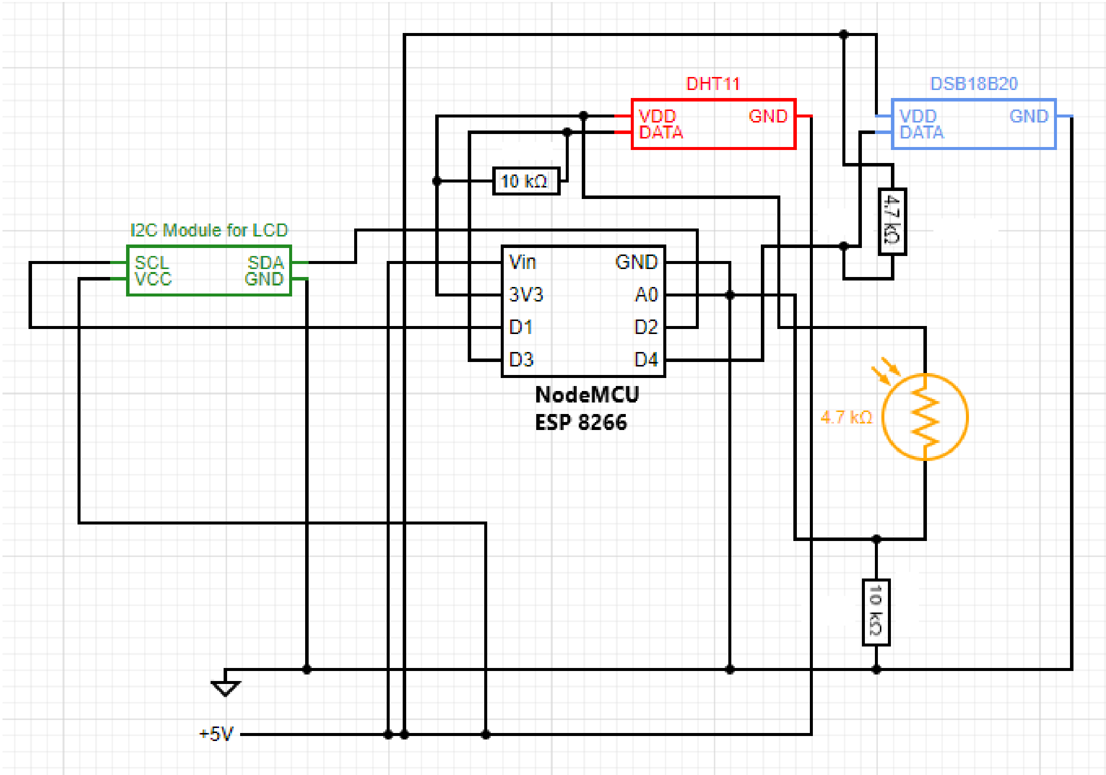

Fig 8. Schematic Circuit Diagram

9.2. NodeMCU ESP8266: Pinout

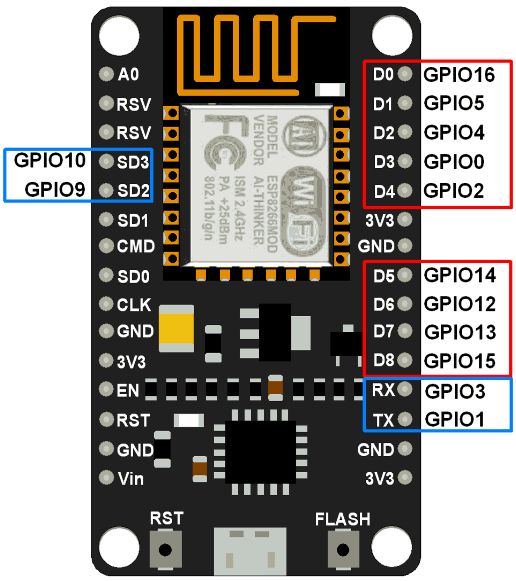

Fig 9. Pinout Diagram of NodeMCU ESP8266

NodeMCU ESP8266 is a microcontroller and IoT (internet of things) platform, having 128 kB memory, 4 MB storage and 13 GPIO (general purpose input-output) pins. It has a default clock frequency of 80 MHz, and a single ADC.

Except for the ultrasonic humidifier, our NodeMCU indirectly powers all the other electronics in the project, through its GND, Vin and 3V3 pins. Two of its digital pins (D1, D2) are used to send data to the LCD screen for display. Two other digital pins (D3, D4) are used to accept data from the humidity sensor and temperature sensor. And finally, one of its analog pins (A0) is used to accept data from the brightness sensor.

9.3. NodeMCU ESP8266: Firmware

The main code for our project is stored as the "Firmware_with_ThingSpeak" INO file. In the spirit of Open Source, our team has made this INO code available for free on GitHub (see Reference [17]).

The main code can be broken up into the following parts:

1. **Include Libraries**: we need to "hash include" various libraries used for connecting our microcontroller to the other devices (LCD screen, DHT11 humidity sensor, DH18B20 temperature sensor, LDR light sensor); and also the ESP8266 and ThingSpeak libraries.
2. **Pin Definitions**: we create variable-names for the analog and digital pins, based on their functions mentioned in §9.2
3. **Global Variables and Defines**: we initialise variables whose values won't change during the Loop section of our code
4. **Object Initialization**: because C++ is an object-oriented language, we must create or initialise the objects of the required classes
5. **Internet and ThingSpeak Configuration**: Because our microcontroller is sending data to ThingSpeak using Wi-Fi, we must enter details such as:
    - the Wi-Fi username and password
    - the ThingSpeak channel number
      (available from ThingSpeak website)
    - the ThingSpeak API key
      (available from ThingSpeak website)
6. **Setup**: this part of the code is run only once, when the microcontroller is powered up.
7. **Loop**: this is the code which is run continuously, as long as the microcontroller is on. It has three main roles:
    - To read the data coming from the brightness, humidity and temperature sensors (sampled once every 10 seconds).
    - To display this data on the LCD screen (which is refreshed every 10 seconds).
    - To send this data to ThingSpeak's cloud storage (sent every 10 seconds)

The reason for everything happening every 10 seconds, is that we have placed a "delay(10*1000)" command in our Loop section, which means that this section only repeats itself once every 10 seconds. The user can change this Sampling Rate if needed.

The flowchart for the "Loop" section of the main code is shown in the figure 10, on the next page.

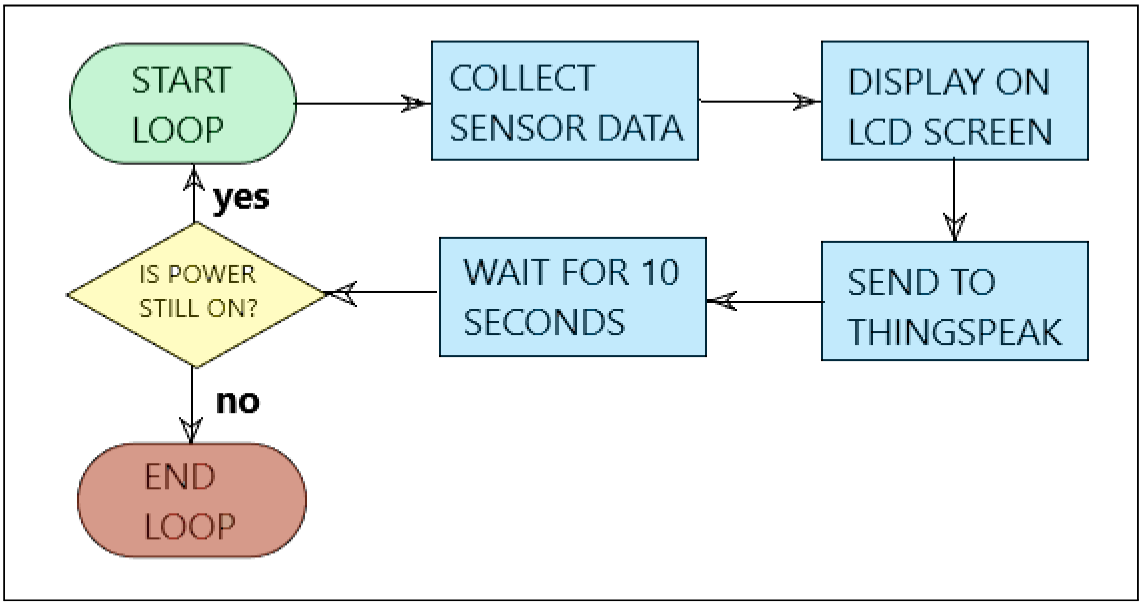

Fig 10. Flowchart for Loop section

10. SOFTWARE REQUIREMENTS

10.1. ThingSpeak

ThingSpeak is free software written in Ruby which allows users to communicate with internet enabled devices. It facilitates data access, retrieval and logging of data by providing an API to both the devices and social network websites. ThingSpeak was originally launched by ioBridge in 2010 as a service in support of IoT applications.

ThingSpeak has integrated support from the numerical computing software MATLAB from MathWorks, allowing ThingSpeak users to analyse and visualise uploaded data using MATLAB without requiring the purchase of a MATLAB licence from MathWorks.

10.2. Arduino IDE

The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. This software can be used with any Arduino board.

Active development of the Arduino software is hosted by GitHub.

11. RESULT

Thus, we have created the first version of a smart aeroponics system, at a total cost of around ₹2,100.

We tested the system out over a two day period. The graphs of the data (humidity, temperature, brightness) collected over that period are shown in figure 10. As mentioned in §6.2, we are not showing all the data in the graphs, but only the average of the data per hour.

Fig 11. Graphs of data collected over two days

In this first trial run for the complete system, the plant growth was suboptimal, as compared to earlier trial runs involving the direct use of liquid water (hydroponics) instead of mist (aeroponics). But, we blame this suboptimal growth not entirely on anything wrong with the system itself, but with our relative lack of experience growing plants using aeroponics.

12. CONCLUSION

As per our experience in this project, we think that Aeroponics should probably not become as widely used as hydroponics or traditional farming methods, because even though it has its purported benefits, the (opportunity) cost of the technical expertise needed in order to set-up and maintain aeroponics systems probably outweigh these benefits. Aeroponics might, however, find a niche audience with hobbyists and urban farmers.

The future of Smart farming seems to be bright, as fields like big data, machine learning and internet of things become more widely adopted. In this project, we have only collected simple “time series” data; that is, measurements of factors such as humidity, pressure, and temperature, at equally spaced points in time. However, in hindsight, we feel that such a data collection method was too simple to actually get any insight into how the various factors were affecting plant growth. Thus, future work involves designing more sophisticated experiments and data collection methods, which can actually help you get insight or build models for how various factors affect plant growth.

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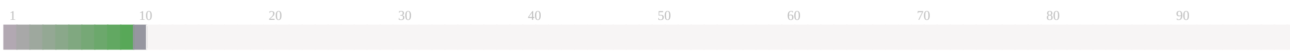

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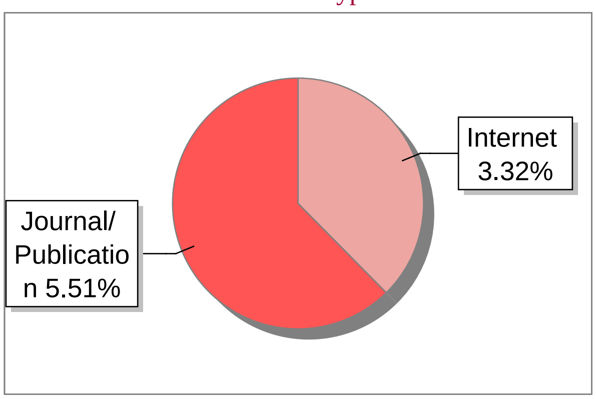

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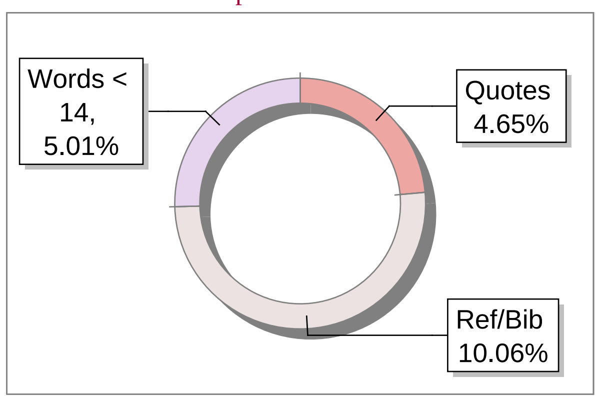

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